

Mar. 12, 2002 Sheet 5 of 20 US 6,356,700 B1

[illegible]

across the electrode sets, domain reversal occurs in regions of high voltage pulses. The range of the applied electric field is several kV per cm to several 100 kV per cm. Domain reversal of the entire crystal wafer so that substantially straight, vertical lines in the z plane are obtained so that the full crystal volume can undergo nonlinear interaction. The patterned high voltage field is applied across the crystal. The processing of E-field poling is described in the articles of Jonas Webjorn et al., Quasi-Phase-Matched Blue-Green Generation in Bulk Lithium Niobate, Electrically Poled via Periodic Electrodes, Electronic Letters, Vol. 30(11), pp. 894-895, May 1995; "Electric Field Induced Periodic Domain Inversion in Nd:LiNbO<sub>3</sub>", Electronic Letters, Vol. 30(25), pp. 2135-2136, Dec. 1995; and L. E. Myers et al., Quasi-Phase-Matched 1.064- $\mu$ m-Pumped Parametric Oscillator in Bulk Periodically Poled LiNbO<sub>3</sub>, Vol. 20(1), pp. 52-54 (Jan. 1, 1995), which are incorporated by reference thereto.

(29) A DFM rare earth doped, periodic poled nonlinear crystal functioning as rare earth doped oscillator may be employed using the architecture of device 35. In this case, a single laser diode provides wavelength,  $\lambda_{\text{sub}1}$ , and device 35 would be a nonlinear material, such as LiNbO<sub>3</sub> or KTP doped with Er, Yb, Pr, or Tm, and is periodically poled, annealed proton exchange, titanium diffusion or E-field poling doped oscillator 35 is provided with reflectors 36A and 36B at output surfaces or may have reflectors positioned in an external cavity forming an external resonator. The input pump beam is partial longer wavelength by pumping the rare earth doped oscillator. pump radiation wavelength within the rare earth doped oscillator difference frequency mixes within the crystal with the internal longer radiation wavelength to generate even longer radiation. generated longer wavelength is internally reflected within the the reflector coatings, which are chosen to provide high reflection longer wavelengths. The periodic poling period is chosen so as to match the DFM interaction. Examples of representative wavelengths for mid-IR wavelengths, for example, useful in spectroscopy are listed below.

(1) TABLE 1 Rare Earth Doped Pumping Wave- Lithium Niobate Wavelength Dopant length,  $\lambda_{\text{sub}1}$ , Range Lasing Wavelength

Nd:sup.3+	805 nm-810 nm	1060 nm	3.3 $\mu$ m-3.4 $\mu$ m
Yb:sup.3+	1120 nm-1150 nm	4.3 $\mu$ m-5.2 $\mu$ m	Tm:sup.3+ 1120 nm-1200 nm
Er:sup.3+	980 nm	1520 nm-1580 nm	2.6 $\mu$ m-2.8 $\mu$ m
Pr:sup.3+	1010 nm-1020 nm	1290 nm-1330 nm	4.2 $\mu$ m-4.4 $\mu$ m

(30) Reference is now made to the embodiment shown in FIG. 1, which is an example of the pumped mid-IR wavelength source 50, which is an example of the

U.S. Patent

Oct. 9, 2001

Sheet 13 of 15

US 6,301,271 B1

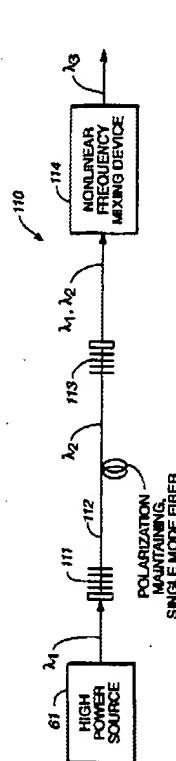


FIG. 19

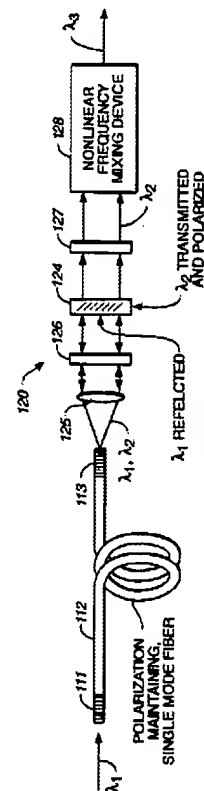


FIG. 20

US-PAT-NO: 6229828

DOCUMENT-IDENTIFIER: US 6229828 B1

TITLE: High power pumped MID-IR wavelength dev  
nonlinear frequency mixing (NFM)

DATE-ISSUED: May 8, 2001

INVENTOR-INFORMATION:

NAME	CITY	STATE
Sanders, Steven	Mountain View	CA
Lang, Robert J.	Pleasanton	CA
Waarts, Robert G.	Fremont	CA

ASSIGNEE INFORMATION:

NAME	CITY	STATE	ZIP
SDL, Inc.	San Jose	CA	95128

APPL-NO: 09/ 123387

DATE FILED: July 27, 1998

PARENT-CASE:

CROSS REFERENCE TO RELATED APPLICATION

This application is a divisional application of application 08/649,560, filed May 17, 1996 now U.S. Pat. No. 5,912,910, incorporated herein by its reference.

INT-CL: [07] H01S003/10

US-CL-ISSUED: 372/22, 372/20, 372/34, 372/37, 372/70, 372/102, 359/326

US-CL-CURRENT: 372/22, 359/326, 372/102, 372/20, 372/34, 372/70, 372/75

FIELD-OF-SEARCH: 372/20; 372/22; 372/6; 372/70; 372/75; 372/102; 359/326

REF-CITED:

U.S. Patent

May 8, 2001

Sheet 13 of 15

US 6,229,828 B1

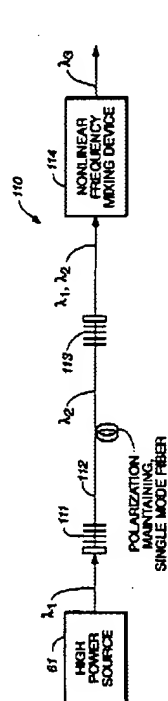


FIG. 19

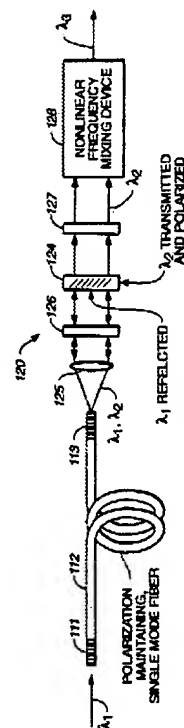


FIG. 20

elliptically polarized eigenmodes for the propagation of light beams in acousto-optical modulator cell 47 comprising an optically active anisotropic crystal. The elliptical polarization of the eigenmodes of acousto-optical modulator cell 47 and the boundary conditions that must be satisfied by electric and magnetic fields of light beams being reflected and refracted at interfaces of optically active anisotropic crystals generate the first subset of the secondary output beams. These certain of the secondary output beams generally have reduced intensities in the apparatus of the first embodiment. The first subset of the secondary beams have directions of propagation different from the directions of propagation of output beams 30 and 31 principally because of properties of birefringent truncated prisms 70 and 80.

(8) Input beam 18 enters acousto-optical modulator cell 47 and, through an acousto-optical interaction with a first acoustic beam, is converted to an intermediate beam. The intensity of the intermediate beam is preferably substantially the same as the intensity of input beam 18. The intermediate beam subsequently passes through a second acoustic beam. By way of an acousto-optical interaction of the intermediate beam with the second acoustic beam, a portion of the intermediate beam is converted into a beam exiting acousto-optical apparatus 40 as one of the output beams 30 and 31 with the remaining non-converted portion of the intermediate beam exiting acousto-optical apparatus 40 as the other of the output beams 30 and 31.

(9) Incomplete conversion of input beam 18 into the intermediate beam generates a second subset of the secondary output beams. The second subset of the secondary beams have reduced intensities in the apparatus of the first embodiment and have directions of propagation different from the directions of propagation of output beams 30 and 31.

(10) Acousto-optical interaction of acoustic beams that result from a portion of the second acoustic beam reflected by absorber 68 and the optical beam remaining as a result of incomplete conversion of input beam 18 into the intermediate beam may generate a third set of beams of the secondary beams. The third set of secondary beams have in the apparatus of the first embodiment reduced intensities, frequencies different from the frequencies of output beams 30 and 31. However, the direction of propagation of the third set of secondary beams is parallel to the directions of propagation of output beams 30 and 31.

(11) Eigenmodes for propagation of light beams in optically active anisotropic crystals generally comprise two modes, a left-handed rotating elliptically polarized mode and a right-handed rotating elliptically polarized mode. The two eigenmodes for light beam propagation in a left-handed rotating positive uniaxial crystal are left-handed and right-handed rotating elliptically polarized modes with the major axes of the eigenmodes coinciding with the directions of polarization of ordinary and extraordinary polarized beams, respectively. The major axes of a left-handed rotating elliptically polarized beam and a right-handed rotating elliptically polarized beam are

U.S. Patent

Dec. 5, 2000

Sheet 9 of 10

6,157,660

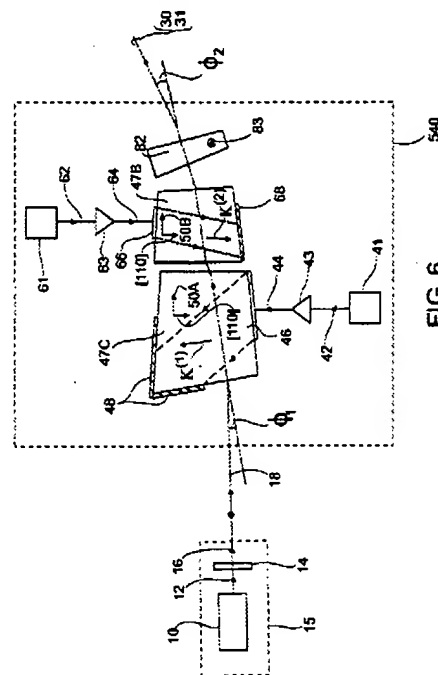


FIG. 6

US-PAT-NO: 5657152

DOCUMENT-IDENTIFIER: US 5657152 A

TITLE: Acoustooptic device

DATE-ISSUED: August 12, 1997

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE
Kadota; Michio	Kyoto	N/A	N/A

ASSIGNEE INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Murata Manufacturing Co., Ltd.	N/A	N/A	N/A	JP

APPL-NO: 08/ 616528

DATE FILED: March 19, 1996

FOREIGN-APPL-PRIORITY-DATA:

COUNTRY	APPL-NO	APPL-DATE
JP	7-091681	March 24, 1995

INT-CL: [06] G02F001/33, G02F001/035

US-CL-ISSUED: 359/305, 359/285, 385/2, 385/7, 310/313D, 310/313B

US-CL-CURRENT: 359/305, 310/313B, 310/313D, 359/285, 385/2, 385/7

FIELD-OF-SEARCH: 359/305; 359/285; 385/2; 385/7; 385/1; 310/313D; 310/313B

REF-CITED:

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PAT-NO	ISSUE-DATE	PATENTEE-NAME
4127320	November 1978	Li
N/A 4418980	December 1983	Keil et al.
N/A 4544229	October 1985	Verber

U.S. Patent Aug. 12, 1997 Sheet 5 of 5 5,657,152

FIG. 7 PRIOR ART

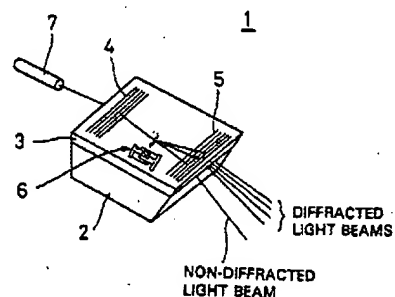
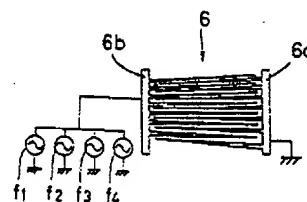


FIG. 8 PRIOR ART



## (2) 1. Field of the Invention

(3) The present invention relates to an acoustooptic device, and particularly to an acoustooptic device which is preferably used as a light deflecting device for a laser printer or other suitable device.

## (4) 2. Description of the Related Art

(5) FIG. 7 is a perspective view showing a conventional acoustooptic device, and FIG. 8 is a diagram showing a main part of the acoustooptic device of FIG. 7. The acoustooptic device deflects light beams by using an interaction between light and ultrasonic waves such as surface acoustic waves. The acoustooptic device 1 includes a  $\text{LiNbO}_3$  layer 2 of Y-cut, and an optical waveguide layer 3 which is formed of a thin film of  $\text{Nb}_2\text{O}_5$  is located on the  $\text{LiNbO}_3$  layer 2. An input grating 4 is located on the principal plane at a light input side of the optical waveguide layer 3 so as to be substantially perpendicular to a light incident direction. An output grating 5 is located on the principal plane at a light output side of the optical waveguide layer 3 so as to be substantially parallel to the input grating 4. The input grating 4 and the output grating 5 collect spatial light beams into the optical waveguide and combine the spatial light beams. The input grating and the output grating 5 are formed as plural grooves which are parallel to one another, or formed of plural rod-shaped electrodes which are parallel to one another.

(6) Further, an interdigital electrode 6 is located on the principal plane of the optical waveguide layer 3 so that a Rayleigh wave, which is a kind of surface acoustic wave, is excited at the intermediate portion between the input grating 4 and the output grating 5. The interdigital electrode 6 is formed of a pair of comb-shaped electrodes 6a and 6b which are mutually inserted into each other (or interdigitated) as shown in FIG. 8. One comb-shaped electrode 6a is grounded while the other comb-shaped electrode 6b is connected to an oscillator for applying a frequency.

(7) In the acoustooptic device 1, a Rayleigh wave is excited so as to have a frequency corresponding to a frequency applied by the interdigital electrode 6. One light beam is incident from a light source 7 into the optical waveguide layer 3 of the acoustooptic device 1. The light beam which is incident from the light source 7 into the optical waveguide layer 3 is diffracted by the Rayleigh wave which is excited by the applied frequency, so that a different light diffraction (deflection) angle can be obtained by changing the frequency applied to the interdigital electrode 6. The acoustooptic device 1 may be used as a light deflection device for a laser printer or the like.

(8) The variation (variable width)  $\Delta\theta$  of a light deflection angle at which the light beam is diffracted in accordance with the variation  $\Delta f$  of the frequency is represented by the following equation:

U.S. Patent

Aug. 12, 1997

Sheet 5 of 5

5,657,152

FIG. 7 PRIOR ART

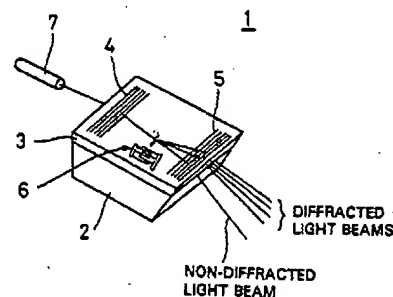
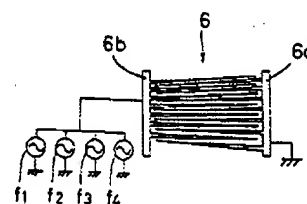


FIG. 8 PRIOR ART



rotation constant in units of degrees per centimeter, and  $k_{\text{sub.opt}}$  is the magnitude of the optical wavevector.

(22) In general, the component of the RF magnetization along the direction of optical propagation results in a traveling refractive index grating which can diffract between orthogonally polarized optical modes. For example, the  $\epsilon_{\text{sub.13}}$  and  $\epsilon_{\text{sub.31}}$  optical permittivity elements of Equation (10) will induce coupling between the TE and TM waveguide modes of an optical wave with a component of travel ( $k_{\text{sub.opt}}$ ) along the Y axis direction in the configuration of FIG. 3. Thus, due to the interaction between the TM input guided optical wave and the MSW, a portion of the TM mode wave is coupled into the orthogonal TE mode while the remaining portion of the guided optical wave remains in the TM mode. The amplitude of the guided optical beam coupled into the TE mode is proportional to the input signal 30 which excites the MSW. Thus the guided optical wave is modulated by the MSW. The optical frequency  $\omega_{\text{sub.d}}$  of the diffracted beam is doppler shifted by the MSW to  $\omega_{\text{sub.d}} = \omega_{\text{sub}} + \Omega_{\text{MSW}}$  when  $k_{\text{sub.d}} = k_{\text{sub.i}} + k_{\text{sub.m}}$  holds or  $\omega_{\text{sub.d}} = \omega_{\text{sub}} - \Omega_{\text{MSW}}$  when  $k_{\text{sub.d}} = k_{\text{sub.i}} - k_{\text{sub.m}}$ .

(23) The growth of the converted mode intensity  $I_{\text{sub.d}}$  with distance  $y$  follows from coupled mode theory as ##EQU4##

(24) In each of the devices 10 and 100 illustrated respectively in FIGS. 1 and 3, a TM polarization mode optical input beam has been converted to an orthogonal TE mode output beam due to the interaction with the MSW in the thin film layer. Alternatively, a TE mode laser beam can be used as an input. In this case, the modulated output beam will be in the orthogonal TM mode. The spatial positions of the input and output beams with regard to the input and output prisms will, of course, change depending on the polarization modes of the various beams.

(25) In the devices 10 and 100 shown respectively in FIGS. 1 and 3, a ground plane for the stripline antenna has been formed by depositing a metallic layer 20 on the lower planar surface 18 of the substrate 12. Alternatively, a ground plane could be formed by depositing a metallic layer on the upper planar surface of an alumina plate (not illustrated) of several mils thickness. The uncoated lower surface of the alumina plate could then be positioned above the upper planar surface 28 of the thin film layer 14 such that the antenna metallization and the magnetic absorber layer are sandwiched between the alumina plate and the thin film layer and are in contact with the plate. In this alternative configuration, the thickness of the alumina plate could be adjusted to optimize the ground plane effect. It should be appreciated that appropriate openings must be formed in the alumina plate to provide clearance for the two prisms which contact the upper surface 28 of the thin film layer. As yet another alternative, the antenna metallization and the magnetic absorber layer could be deposited on the lower surface of the alumina plate with the upper surface of the plate being coated with the ground plane metallization.

U.S. Patent Mar. 11, 1986 Sheet 1 of 4 4,575,179

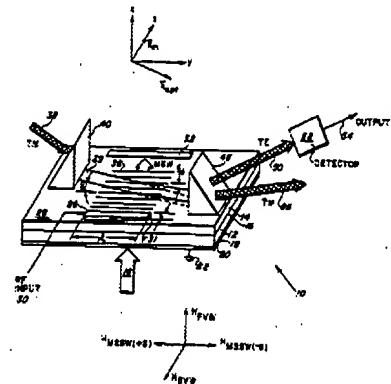


FIG. 1







19, 2001, and U.S. Provisional Patent Application, Serial No. 60/277,480, entitled "LENS FOR AN OPTICAL SWITCH" filed Mar. 19, 2001, the contents of both of which are hereby incorporated by reference.

#### BRIEF SUMMARY:

#### FIELD OF THE INVENTION

[0002] The present invention is generally related to fiber optic switches and more particularly relates to multi-port, non-blocking optical switches.

#### BACKGROUND

[0003] Continuing innovations in the field of fiber optic technology have contributed to the increasing number of applications of optical fibers in various technologies. With the increased utilization of optical fibers, there is a need for efficient optical systems that assist in the transmission and the switching of optical signals. For example, there is presently a need for optical switches that direct the light signals from a set of input optical fibers to any of several output optical fibers, without converting the optical signal to an electrical signal. Light in this sense generally refers to the propagation of electromagnetic radiation and is not limited to the visible spectrum.

[0004] Various techniques may be utilized to couple optical fibers with a switch. For example, information may be digitally switched by converting the optical signal into a digital electrical signal, electrically routing the signal, and then regenerating an optical signal. This complex process offers the greatest traffic control but is very expensive and unnecessary for the majority of traffic passing through a switching node. Therefore, low-port-count MEMS-based optical switches are commonly used in communications systems to switch light from a plurality of input waveguides to a plurality of output waveguides without first converting the optical signal to an electrical signal. Such optical switches use MEMS mirrors as a reflective element, moving the mirror in or out of the path of a beam of light to redirect the optical signal path between stationary waveguides or collimating optics.

[0005] Many types of optical switches that utilize MEMS micro-mirrors have been proposed and tested. Two-dimensional arrays of bi-state micro-mirrors have been constructed that enable digital switching of optical signals. Monolithically interconnected arrays of 2.times.2 waveguide switches with thermal or electric field induced switching can provide the same function. This class of switches is commonly referred to as 2D due to their switching in a two-dimensional or planar surface. For a configuration with N inputs and N outputs, N.sup.2 switching nodes are required.

Patent Application Publication Nov. 28, 2002 Sheet 1 of 24 US 2002/0176657 A

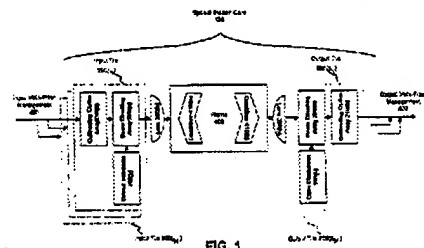


FIG. 1

## BACKGROUND ART

[0003] Modern fiber optical communications systems direct optical signals over multiple fibers. Such systems require optical switches to direct light beams from any given fiber in an input fiber array to any given fiber in an output array. One class of optical switches uses an approach called beam steering. In beam steering, the light from the fiber is selectively deflected or steered by one or more movable optical element from the input fiber to the output fiber. Suitable optical elements include microelectromechanical system (MEMS) mirrors. MEMS mirrors are usually actuated by magnetic interaction, electrostatic, or piezoelectric interaction. Typically, two sets of moveable mirrors are used to steer the beam. Each fiber has a small "acceptance window". The fiber only efficiently couples light that is incident within a narrow range of angles and positions. Although a single mirror will generally direct the beam from an input fiber to the correct output fiber, two mirrors ensure that the light beam enters the output fiber at the correct angle. If the beam makes too large an angle with the axis of the fiber, light from the beam will not couple properly to the fiber, i.e. there will be high losses.

[0004] Optical switches using the steering-beam approach have been demonstrated in two primary implementations. The first uses linear arrays of mirrors with a single angular degree of freedom. Combining two such mirror arrays as shown in FIG. 1 allows an implementation of an N.times.N optical switch, where the number of input and output channels is equal to the number of mirrors in each array. The first array steers an optical beam from an input fiber to the appropriate mirror on the second array, which then steers the beam into the corresponding output fiber. This implementation uses simple single-axis mirrors; however, it is limited in its scalability since the optical path between fibers becomes unreasonably large for large port counts (e.g. >32.times.32), increasing the loss of the switch

[0005] The second implementation depicted in FIG. 2 uses two sets of 2-dimensional mirror arrays, each mirror having two angular degrees of freedom. The input and output fibers are each also arranged in a 2-dimensional grid with the same dimension as the mirror arrays. The mirrors in the first mirror array steer the optical beams from the fibers onto the appropriate mirror in the second mirror array which then steers the beam into the corresponding fiber. This approach is considerably more scalable, since, due to its 2-dimensional layout, the size of the mirror and fiber arrays grows as the square root of the number of input/output ports, which is much slower than in the case of a 1-dimensional grid. Therefore, switches with much larger port count (>2000.times.2000) are possible. However, this implementation requires the mirrors to rotate about two different axes. Such mirrors are considerably more difficult to design, fabricate, and control.

[0006] There is a need, therefore, for a beam steering apparatus that uses single axis optical elements to switch optical signals in an N.times.N fiber array

Patent Application Publication Sep. 24, 2003 Sheet 1 of 4 US 2002/0135855 A

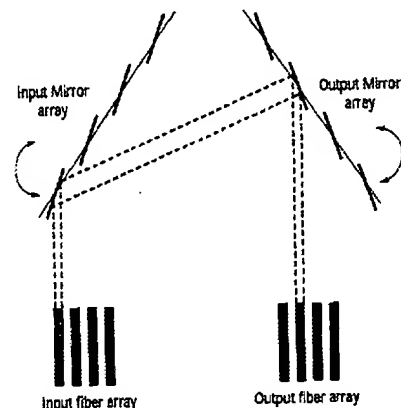


Fig. 1 (Prior Art)

4408a and output from the optical I/O port.

[0012] In FIG. 44(B), the optical deflector 4402 comprises the optical fiber 4408 inserted through the I/O port, a collimating lens 4410, a fixed mirror 4412, and a movable mirror 4414.

[0013] A light beam from the I/O port leaves from the end of the optical fiber 4408 that is housed in the optical deflector 4402. This light beam is focused or condensed by the collimating lens 4410 and reflected or deflected by the fixed mirror 4412 into the movable mirror 4414 at which it is reflected at a given deflection angle. The movable mirror 4414 has two rotation axes that are perpendicular to the incident direction of a light beam so as to be movable on two axes. The rotation of the movable mirror 4414 may be adjusted by an ordinary technique. Thus, the movable mirror 4414 is able to reflect the light beam to the mirror 4404 at a given deflection angle. The mirror 4404 then reflects the light beam toward the optical deflector 4402a.

[0014] The light beam put into the light deflector 4402a travels in the direction opposite to that of FIG. 44(B) and is deflected by the movable mirror 4414. Then, it is reflected by the fixed mirror 4412, condensed by the collimating lens 4410, and output from the I/O port via the optical fiber 4408a. The deflection angle is adjusted at the movable mirror 4414 to input the light beam into the optical fiber 4408a.

[0015] As has been described above, this optical switch is composed of one stage of optical deflectors using a movable mirror or lens to control the direction of a light beam into the predetermined I/O port. This optical switch employs 3-D wiring or interconnection so that it is easy to increase the number of ports.

[0016] However, the conventional optical switch requires very high precisions with which the light beam is deflected by a single deflector. Consequently, it has the following disadvantage.

[0017] The diameter of optical fibers for usual optical communication systems is approximately eight microns. If a light beam is input with a positional error of about one micron, a loss of one dB or more is generated, presenting a practical problem. The distance between the output ports required for mounting is a few 100 microns or more so that even a piece of two-channel equipment requires a precision of about 0.1% in deflection angle. If the equipment has tens of channels or more, the required precision is in the order of 10<sup>-4</sup>. The 100-channel equipment using movable mirrors requires a precision of about 1% in deflection angle. The equipment of 1000 channels or more requires a precision of 0.3%.

[0018] In order to solve the problem, it has been proposed to superimpose a position detecting signal on the light beam to detect the deflection angle and

Patent Applications Publication Jul. 18, 2002 Sheet 1 of 43 US 2002/0093723 A

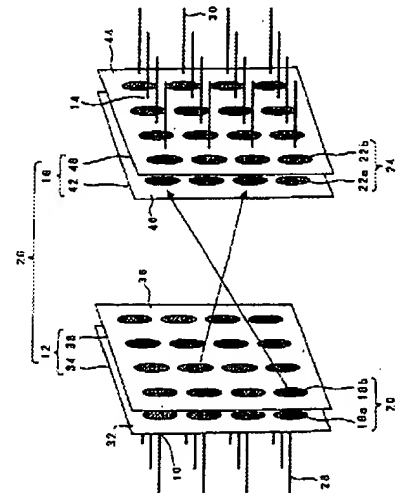


FIG. 1

## BACKGROUND OF THE INVENTION

## [0002] 1. Field of the Invention

[0003] The present invention relates generally to micro-electromechanical (MEMS) devices and, in particular, to arrayed magnetically actuated MEMS devices such as arrayed mirrors used in optical switches.

## [0004] 2. Description of Related Art

[0005] FIG. 1 schematically illustrates an example of an optical cross-connect 12 of an optical switch. The cross-connect 12 includes an array of collimators or other beam-forming devices, represented by grid 14, and forms incoming optical communications signals into beams that impinge on an array of selectively moveable reflectors or mirrors represented by grid 16. Each beam from grid 14 has its own corresponding moveable mirror on grid 16.

[0006] The moveable mirrors of grid 16 are controllably positioned so as to individually direct the respective beams from grid 14 to respective moveable mirrors of a second array of moveable mirrors, represented by grid 18. The moveable mirrors of grid 18 are positioned so as to individually direct the beams received from grid 16 to respective beam receivers of an array of beam receivers represented by grid 20. The beam receivers may take various forms, such as transducers, lenses or optical elements for coupling the respective beams into respective optical fibers, waveguides, or the like. As with grids 14 and 16, each moveable mirror of grid 18 is associated with a particular beam receiver of grid 20, so that each receiver receives beams on a single axis. A representative signal path from grid 14 to grid 20 is indicated by arrow 22.

[0007] Attempts have been made previously to fabricate arrays of mirrors such as those represented by grids 16 and 18 using MEMS technology, in which silicon processing and related techniques common to the semiconductor industry are used to form micro-mechanical devices. For switches such as that shown in FIG. 1, it is desirable to have an array of moveable mirrors that are both densely packed and easily controlled.

[0008] As is known in the art, movable mirrors can be actuated or controlled in a variety of ways including through electromagnetic actuation, electrostatic actuation, piezoelectric actuation, stepper motors, thermal bimorph and comb-drive actuation.

[0009] FIG. 2 illustrates an electro-magnetically actuated single-mirror device 30 in accordance with the prior art. The mirror device 30 includes a mirror 32 movably supported on a gimbal structure 34. The mirror 32 includes a reflective surface 33, which is on the same side of the mirror as the actuation coils.

Parent Application Publications May 2, 2002 Sheet 3 of 25 US 2002/0059744 A

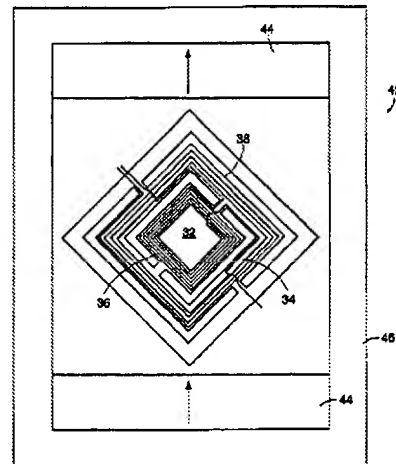


FIG. 3  
PRIOR ART

Exemplary Claim Number: 1

Number of Drawing Sheets: 4

## BRIEF SUMMARY:

## (1) FIELD OF THE INVENTION

(2) This invention relates generally to fiber optic communications. More particularly, the invention relates to optical switches for NxN arrays of fibers.

## (3) BACKGROUND ART

(4) Modern fiber optical communications systems direct optical signals over multiple fibers. Such systems require optical switches to direct light beams from any given fiber in an input fiber array to any given fiber in an output array. One class of optical switches uses an approach called beam steering. In beam steering, the light from the fiber is selectively deflected or steered by one or more movable optical element from the input fiber to the output fiber. Suitable optical elements include microelectromechanical system (MEMS) mirrors. MEMS mirrors are usually actuated by magnetic interaction, electrostatic, or piezoelectric interaction. Typically, two sets of moveable mirrors are used to steer the beam. Each fiber has a small "acceptance window". The fiber only efficiently couples light that is incident within a narrow range of angles and positions. Although a single mirror will generally direct the beam from an input fiber to the correct output fiber, two mirrors ensure that the light beam enters the output fiber at the correct angle. If the beam makes too large an angle with the axis of the fiber, light from the beam will not couple properly to the fiber, i.e. there will be high losses.

(5) Optical switches using the steering-beam approach have been demonstrated in two primary implementations. The first uses linear arrays of mirrors with a single angular degree of freedom. Combining two such mirror arrays as shown in FIG. 1 allows an implementation of an NxN optical switch, where the number of input and output channels is equal to the number of mirrors in each array. The first array steers an optical beam from an input fiber to the appropriate mirror on the second array, which then steers the beam into the corresponding output fiber. This implementation uses simple single-axis mirrors; however, it is limited in its scalability since the optical path between fibers becomes unreasonably large for large port counts (e.g. >32.times.32), increasing the loss of the switch.

(6) The second implementation depicted in FIG. 2 uses two sets of 2-dimensional mirror arrays, each mirror having two angular degrees of freedom. The input and output fibers are each also arranged in a 2-dimensional grid with

U.S. Patent Dec. 11, 2001 Sheet 2 of 4 US 6,330,102 B

